MULTIMEDIA UNIVERSITY

STUDENT ID NO

MULTIMEDIA UNIVERSITY

FINAL EXAMINATION

TRIMESTER 2, 2018/2019

EEN7026 – SEMICONDUCTOR PHYSICS AND MATERIALS

4 MARCH 2019
2.30 p.m. - 5.30 p.m.
(3 Hours)

INSTRUCTIONS TO STUDENTS

1. This Question paper consists of 8 pages with 6 Questions only.
2. Attempt **All** questions. The distribution of the marks for each question is given.
3. Please write all your answers in the Answer Booklet provided.

Useful constants and coefficients:

Physical Constants

Boltzmann's constant (k)	1.3807×10^{-23} JK^{-1} 8.617×10^{-5} eVK^{-1}
Planck's constant (h)	6.626×10^{-34} Js
Thermal voltage@300K kT/e kT	0.0259 V 0.0259 eV
Electron mass in free space$\left(m_e\right)$	9.10939×10^{-31} kg
Electron charge$\left(e\right)$	1.60218×10^{-19} C
Effective density of states in the conduction band for Si (N_c)	2.8×10^{19} cm^{-3}
Effective density of states in the Valence band for Si (N_v)	1.2×10^{19} cm^{-3}
Permeability of free space$\left(\mu_0\right)$	$4\pi\times10^{-7}$ Hm^{-1}
Permittivity of free space of free space$\left(\varepsilon_0\right)$	8.85×10^{-12} Fm^{-1}
Avogadro's number$\left(N_A\right)$	6.022×10^{23} atoms/mol

Question 1 [16 marks]

(a) (i) Quantum wave is based on ideas of the wave nature of matter, using the de Broglie's hypothesis and the wave equation to show that the time-independent Schrödinger wave equation is $-\frac{\hbar^2}{2m}\frac{\partial^2\psi(x)}{\partial x^2}+V(x)\psi(x)=E\psi(x)$.

[5 marks]

(ii)The energy of a free electron confined in one-dimensional finite potential well, as shown in Figure Q1(a), is quantized and a is the width of the well. Assume that in region I and III, $V(x<0 \quad \& \quad x>a)=V_0$ and the potential in the well region II, $V(0<x<a)=0$. Sketch the first three allowed energy levels and the corresponding wave functions for the electron in this finite potential well and briefly explain your diagrams.

[6 marks]

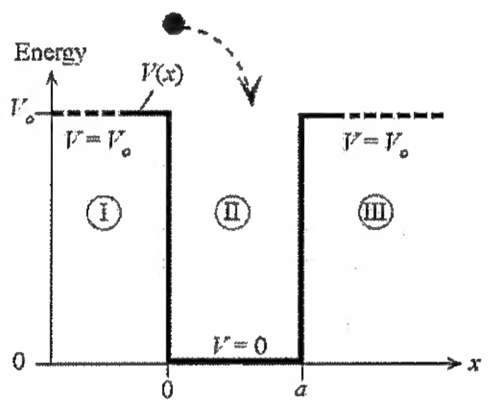

Figure Q1(a)

(b) (i) Define the Pauli Exclusion Principle. [1 mark]

(ii) The state of an individual electron in an atom can be completely described by a set of four quantum numbers. Define these quantum numbers and their relationships.

[4 marks]

Continued....

Question 2 [18 marks]

(a) Copper (Cu) has the Face-centered Cubic (FCC) crystal with a lattice constant $a = 0.362$ nm, as shown in Figure Q2(a). Atomic mass of Cu is 63.55 g mol^{-1}.

(i) Sketch the (100) and (110) planes in the FCC lattice. [3 marks]

(ii) Find the planar concentrations as the number of atoms per nm^2 of the (100) and (110) planes.
[4 marks]

(iii) Determine the effective number of atoms per unit cell and atomic concentration of Cu. [2 marks]

(iv) Calculate the density of Cu crystal. [2 marks]

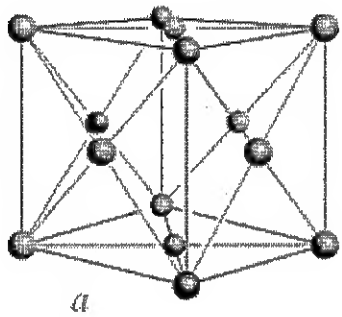

Figure Q2(a)

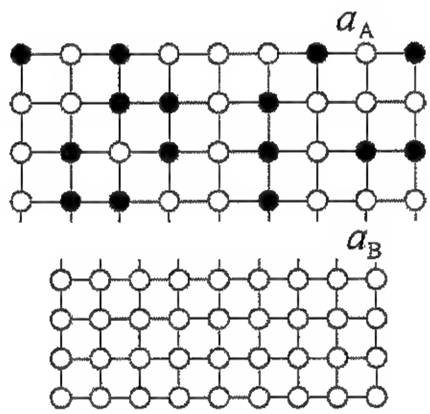

Figure Q2(b)

(b) The quality of a material near heterointerfaces depends strongly on the ratio of lattice constants for the two materials, as shown in Figure Q2(b), where $a_A > a_B$.

(i) Give an example for a lattice-mismatched structure. [1 mark]

(ii) With the aid of a simple diagram, explain why there is a critical thickness for which the lattice-mismatched structure is formed without defects.
[6 marks]

Continued....

Question 3 [20 marks]

(a) Figure Q3(a) shows the drift velocity of electrons and holes in bulk GaAs and Si as a function of applied electric field at 300 K.

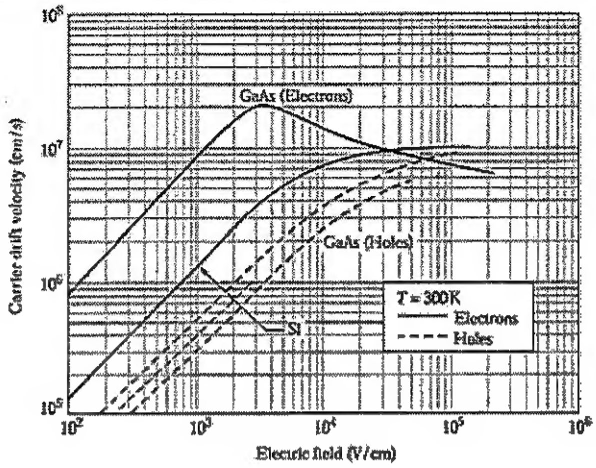

Figure Q3(a)

(i) Give FOUR different types of carrier scattering processes in GaAs and Si.[2 marks]

(ii) Sketch the constant energy surface near the conduction band edge of semiconductor GaAs and Si in three dimensional k-space. Briefly explain your diagrams. [4 marks]

(iii)Explain why the electron drift velocity in Si are relatively lower as compare to GaAs at electric fields below 10^4 V/cm. [4 marks]

(iv)With the aid a simple conduction band diagram of GaAs, briefly explain the decrease of electron drift velocity with increasing electric field. [5 marks]

(b) Consider a conduction electron in Si has a thermal energy kT, related to its mean thermal velocity by $E_{th} = m_e^* v_{th}^2/2$. This electron is placed in an electric field of 100 V/cm. Given that the electron mobility, μ_n = 1350 cm^2/V-s and the electron effective mass, $m_e^* = 0.26m_0$ $\left(m_0 = 9.1\times10^{-31}\,kg\right)$.

(i) Calculate the drift velocity of the electron and compared to its thermal velocity. [3 marks]

(ii) Repeat your calculation in (ii) for a field of 10^4 V/cm, using the same value of μ_n. Comment on the actual mobility effects at this electric field as shown in Figure Q3(a). [2 marks]

Continued....

Question 4 [18 marks]

(a) When Ga and As atoms are brought together to form the GaAs crystal, as shown in Figure Q4(a) in two-dimensional representation, the bonding is similar to that in the Si crystal. The crystal structure is not that of diamond but it is of zinc blende.

(i) What is the average number of valence electrons per atom in the GaAs crystal? [1 mark]

(ii) What will happen if Te from Group VI is substituted for an As atom in the GaAs crystal? [2 marks]

(iii)What will happen if Zn from Group II is substituted for a Ga atom in the GaAs crystal? [2 marks]

(iv)What will happen if Si, from Group IV, is substituted for an As atom in the GaAs crystal? [2 marks]

(v) What will happen if Si, from Group IV, is substituted for a Ga atom in the GaAs crystal? [2 marks]

(vi)What is an amphoteric dopant? Explain briefly how the same dopant can be used to produce a p-n junction.

[3 marks]

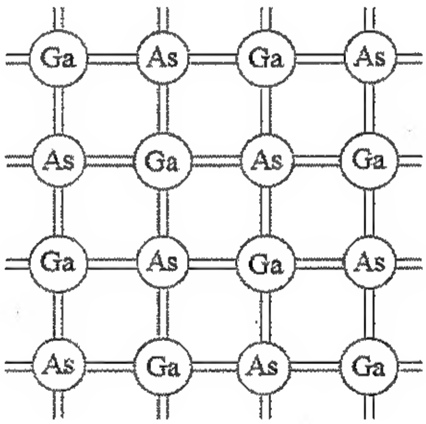

Figure 4Q(a)

(b) Briefly explain, with the aid of diagram, the modulation doping in heterostructure semiconductor and its advantages.

[6 marks]

Continued....

Question 5 [14 marks]

(a) Explain why silicon is the material of choice in integrated circuits (ICs) fabrication.
[3 marks]

(b) Figure Q5(b) illustrates the Czochralski setup for single crystal growth. Briefly describe the Czochralski process steps to grow the silicon bulk crystal and its advantages.
[5 marks]

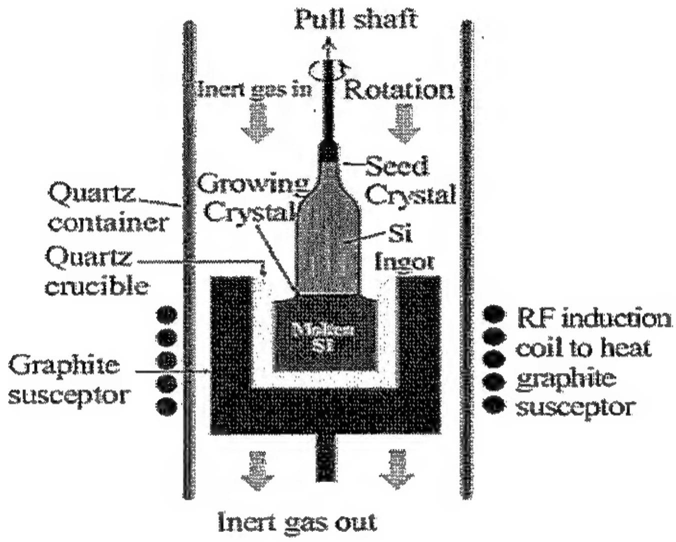

Figure Q5(b)

(c) The Float Zone (FZ) grown crystal is preferred over that grown by Czochralski (CZ) technique for the fabrication of high voltage semiconductor devices. Explain the better-quality of FZ over CZ grown crystal.
[3 marks]

(d) Define epitaxy and briefly explain the advantages of epitaxy wafer compare to bulk wafer.
[3 marks]

Continued....

Question 6 [14 marks]

(a) State the FOUR categories of defects in a crystal according to their geometry and name the type of defect A, B, C, D, E, F, and G in the Figure Q6(a).

[6 marks]

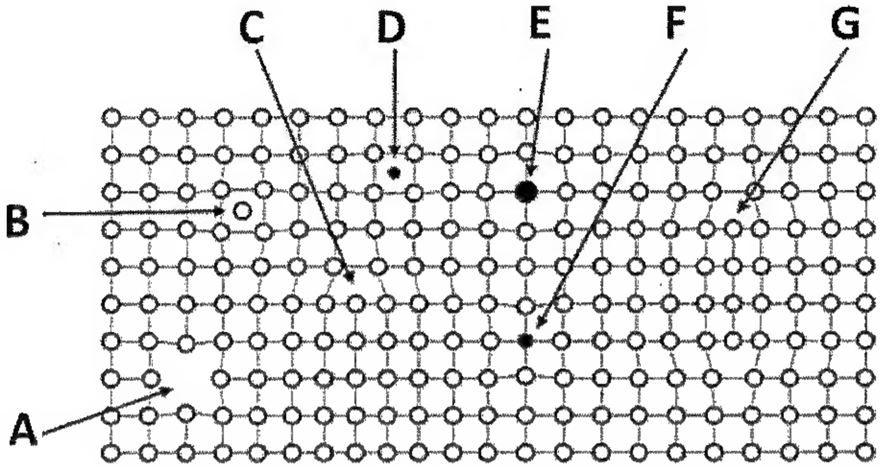

Figure Q6(a)

(b) In semiconductor device fabrication, Silicon is usually doped by the diffusion of impurities at high temperatures, typically 1250 – 1450 K. The equilibrium concentration of vacancies (point defects) is given by $N_d = N_{sites}\exp\left(-\frac{\Delta E_d}{kT}\right)$, where N_{sites} the site density or atomic concentration for Si crystal and the energy of vacancy formation is $\Delta E_d = 3.6$ eV. Given that for Si, the atomic mass $M_{at} = 28.09$ g mol^{-1} and density $\rho = 2.33$ g cm^{-3}.

(i) Determine the atomic concentration of Si crystal at 300 K. [2 marks]

(ii) Determine the equilibrium concentration of vacancies in Si crystal at 1273 K. Neglect the change in the density with temperature.

[2 marks]

(iii) Assume a typical dislocation site due to the segregation of vacancies initially formed at 1300 K has 300 missing atoms, determine the density of dislocations in the semiconductor.

[1 mark]

(c) Briefly explain the intrinsic gettering process during wafer fabrication steps to remove device-degrading impurities in the active circuit regions of the Si wafer.

[3 marks]

End of the paper